



**Jet Propulsion Laboratory**  
California Institute of Technology

# Multiple Scattering and Non-Uniform Beam Filling in DPR observations

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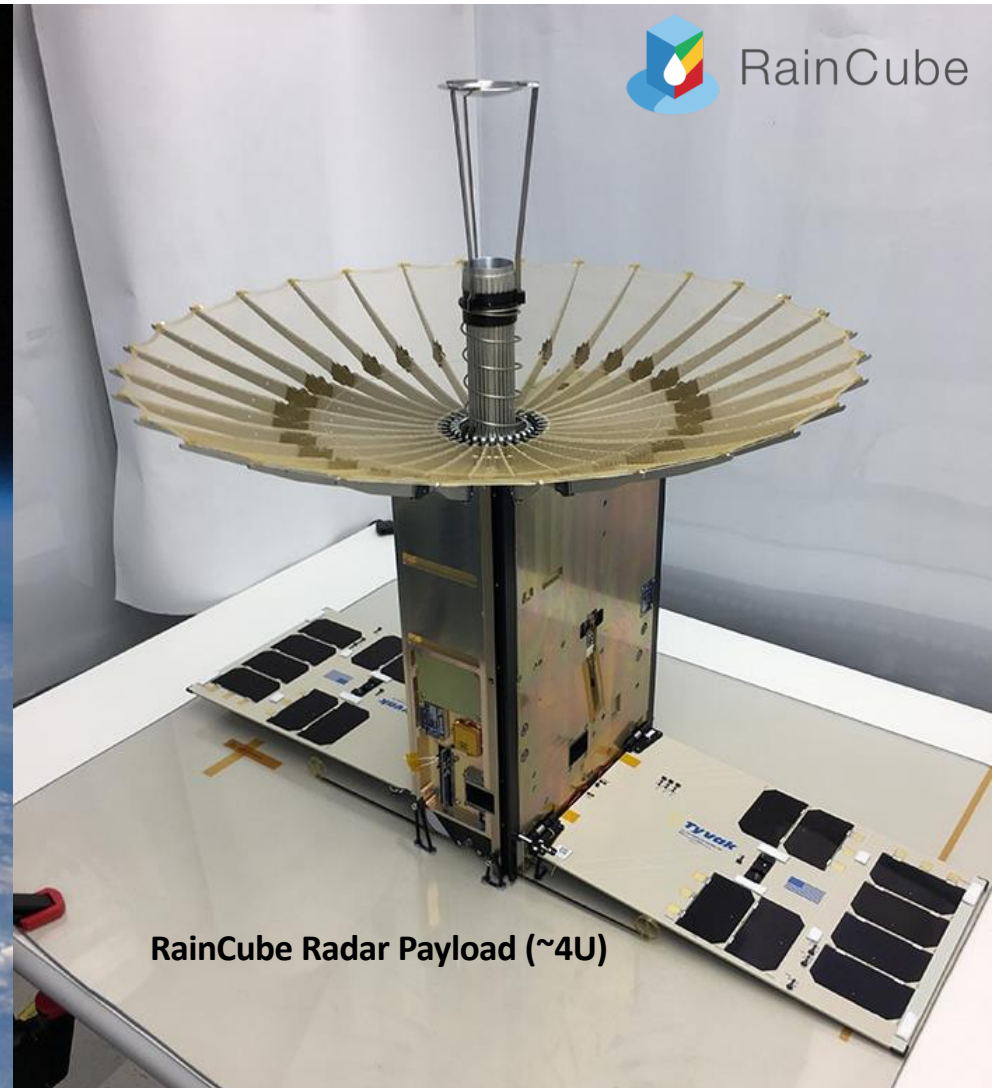
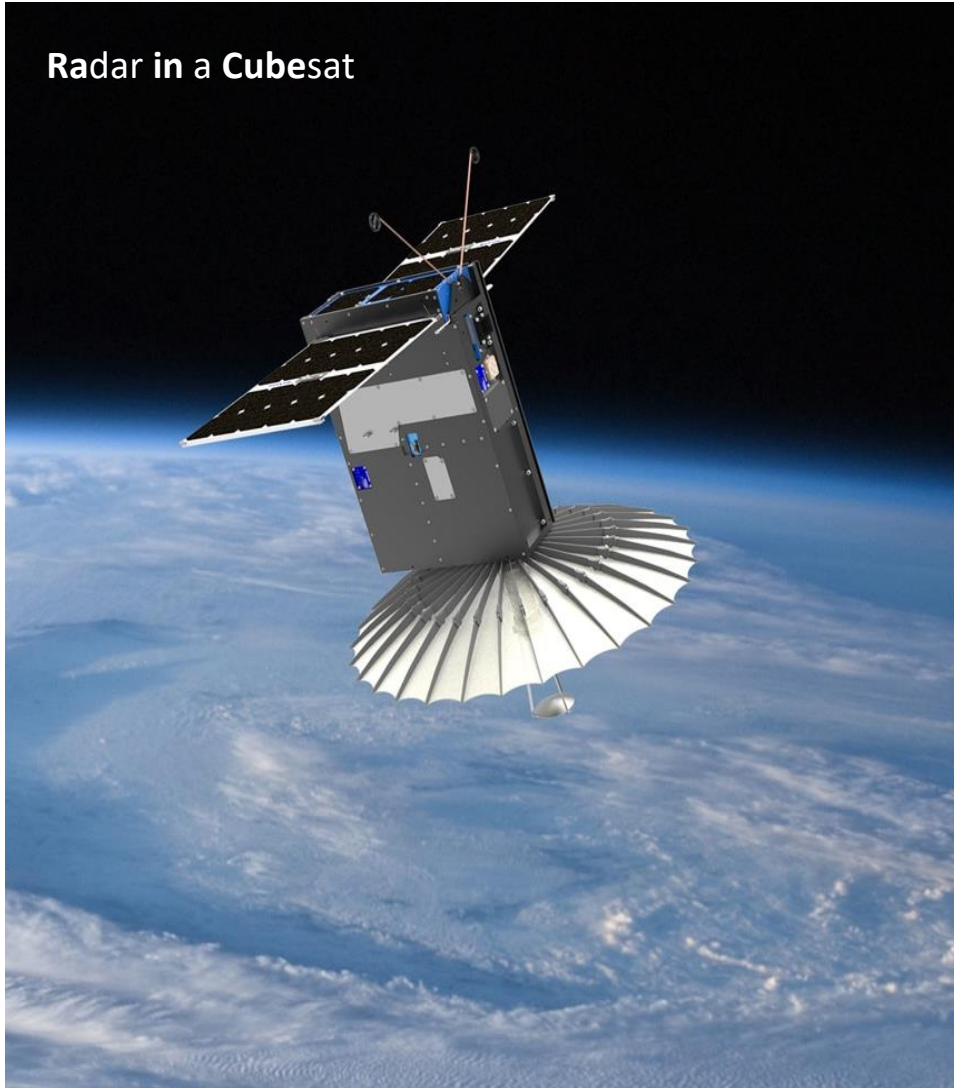
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4 Advanced Radar Research Center, National Weather Center, Norman, Oklahoma, USA

5 NOAA/National Severe Storms Laboratory, Norman, Oklahoma, USA

6 George Mason University, Fairfax Va/NASA-GSFC, USA

## Radar in a Cubesat



RainCube Radar Payload (~4U)



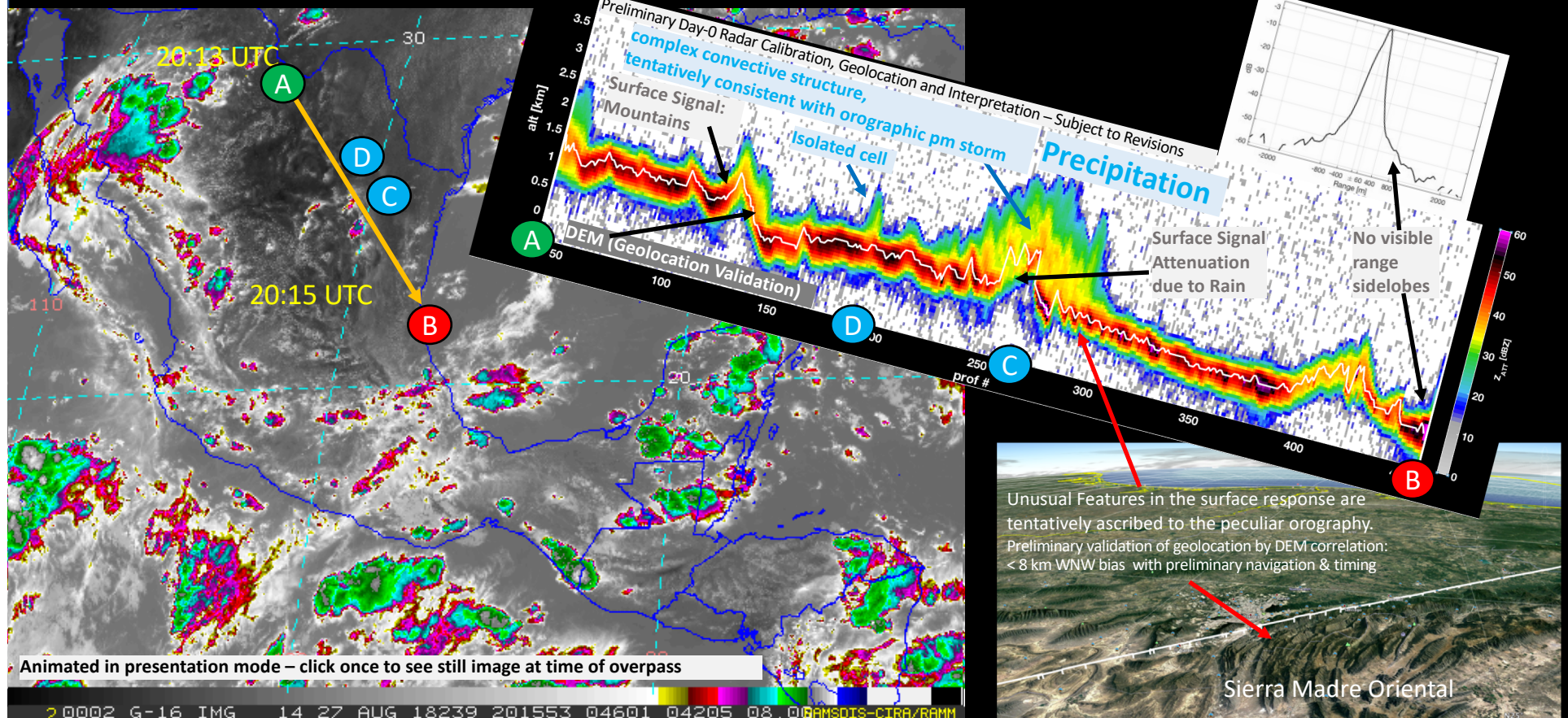
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## RainCube Tx Operation #23 - August 27 , 2018 – 20:14 UTC

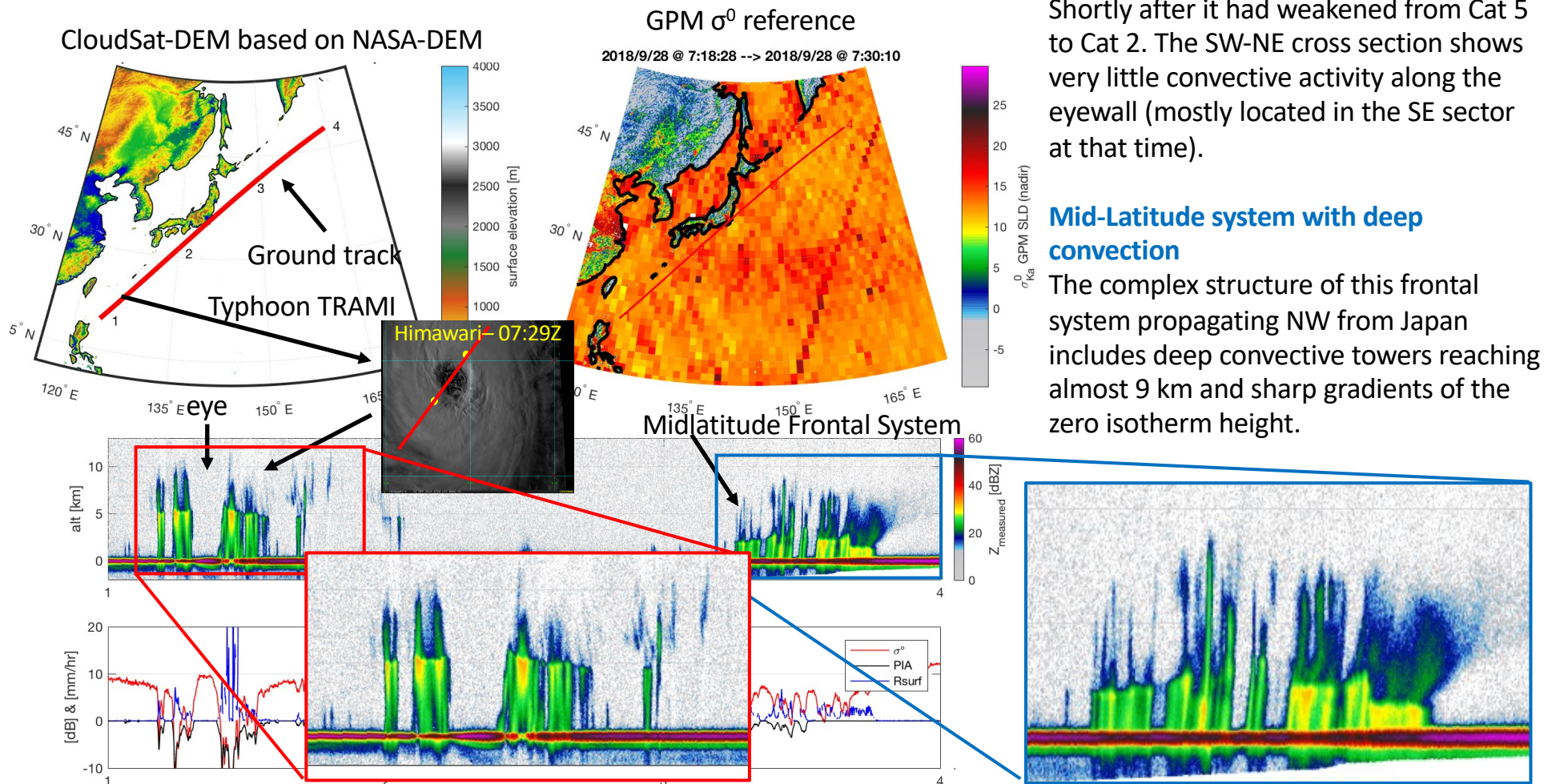


RainCube

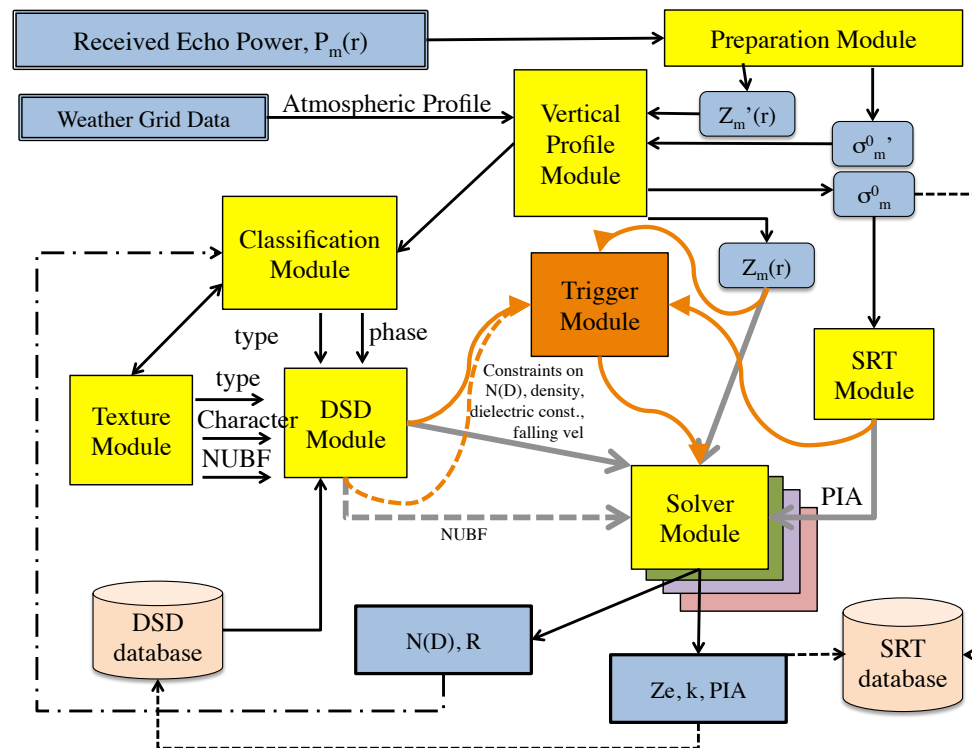
First successful operation in Nadir Pointing & first detection of rain over the Sierra Madre Oriental, near Monterrey, Mexico. Fast growing orographic precipitation developed shortly before RainCube's pass which overflowed its north-eastern edge



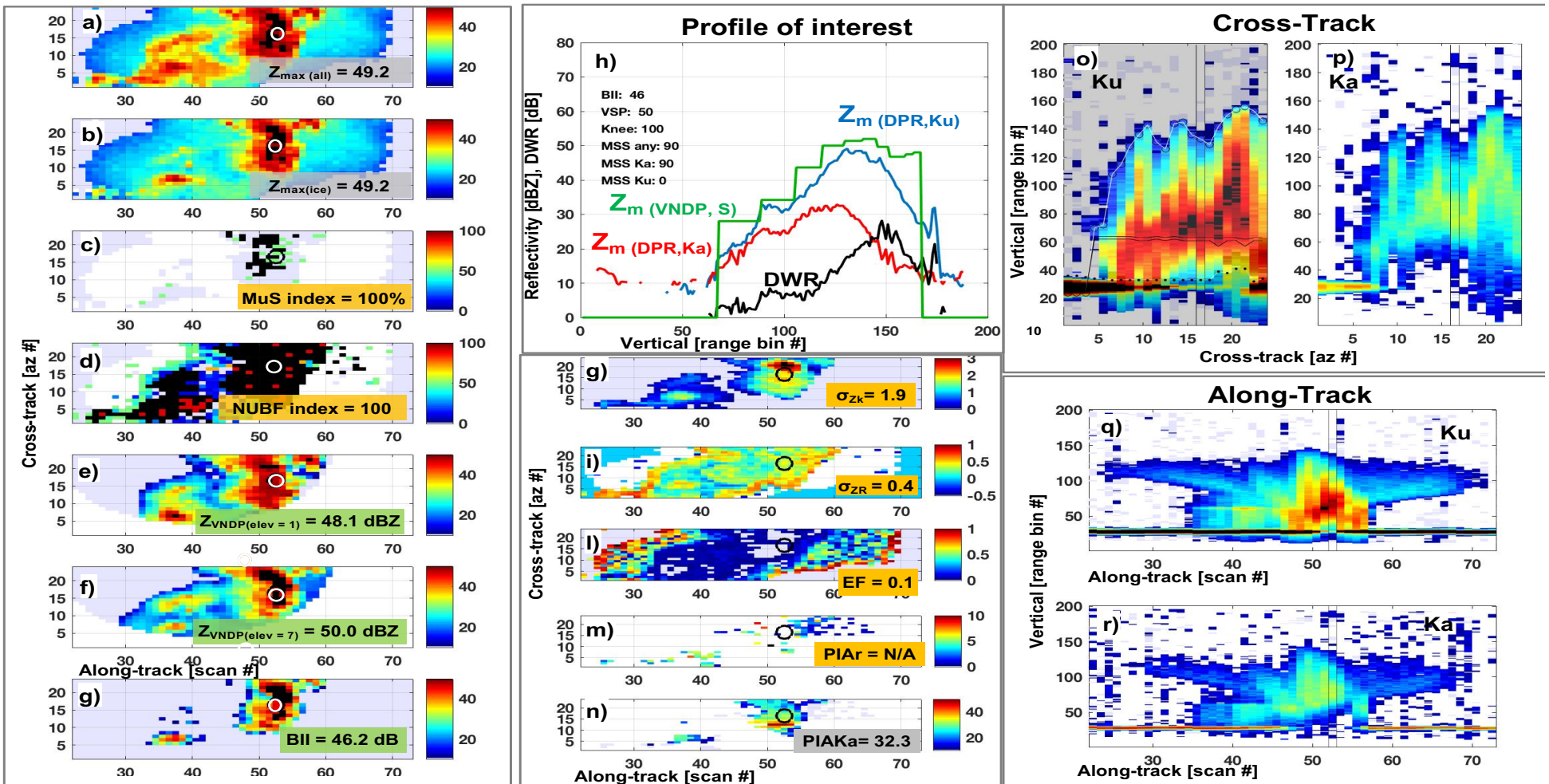
# RainCube – September 28, 2018



# Trigger Module in DPR processing

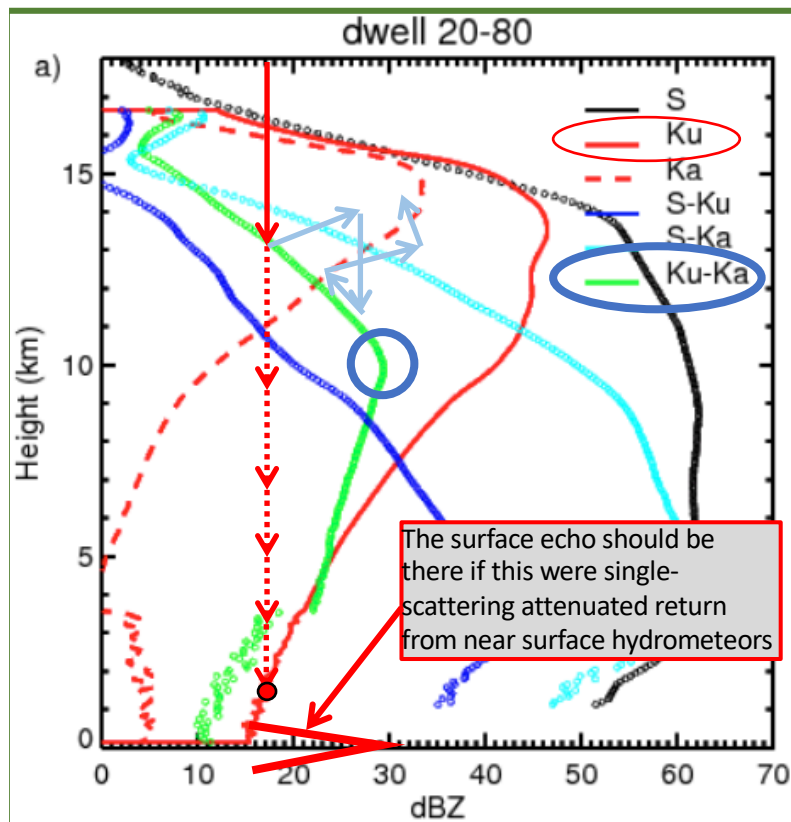


# Trigger Module products

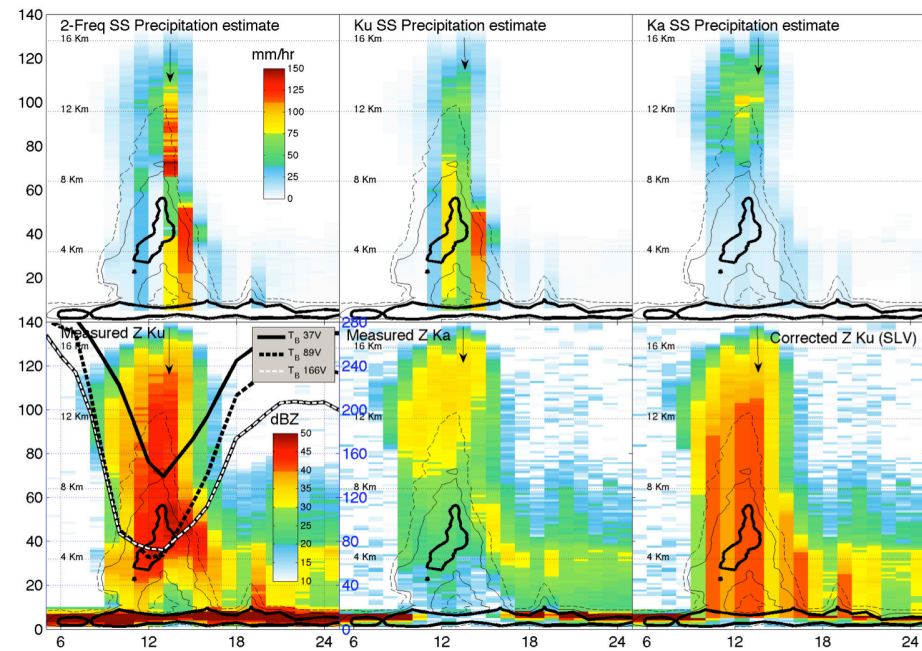


# MS short summary

1) When the pulse emitted by the radar encounters a region with significant attenuation (e.g.,  $> 1$  dB/Km) AND large albedo (e.g.,  $> 0.5$ ) most of its energy is scattered in all directions and further interacts with surrounding particles. The path length resulting from the multiple events can be erroneously interpreted under the single scattering assumption as the echo of a target further away from the radar.



2) Where is the surface return? How can there be an attenuated echo from rain at 0 m above the surface...but no surface? At Ku and Ka band the surface echo persists longer than the near surface rain because it is stronger to start with.

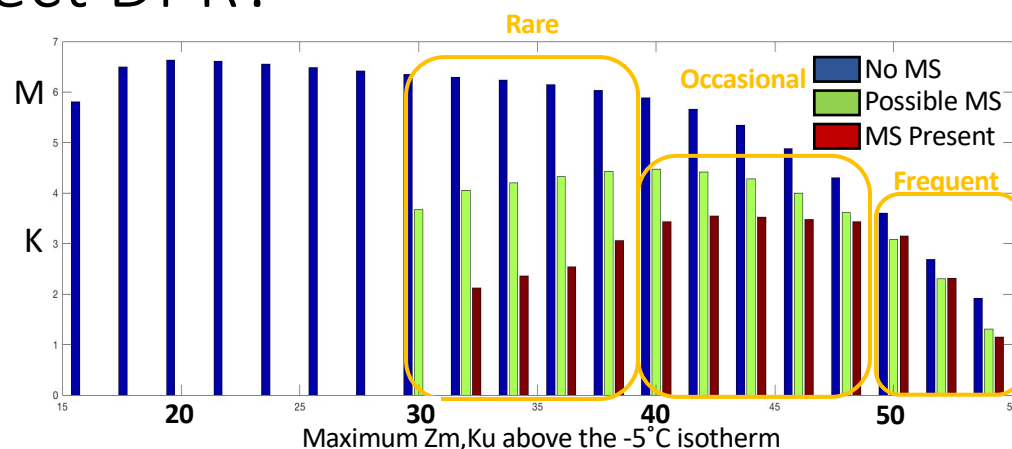


# How often does MS affect DPR?

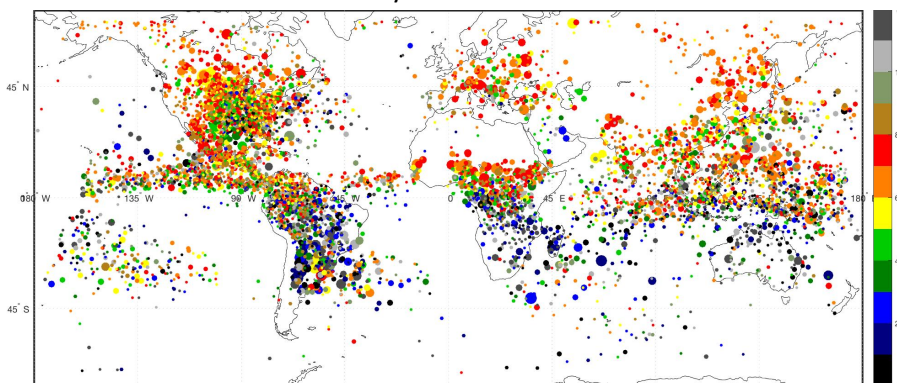
Test dataset spans 4 years and all seasons

> 600K storms examined

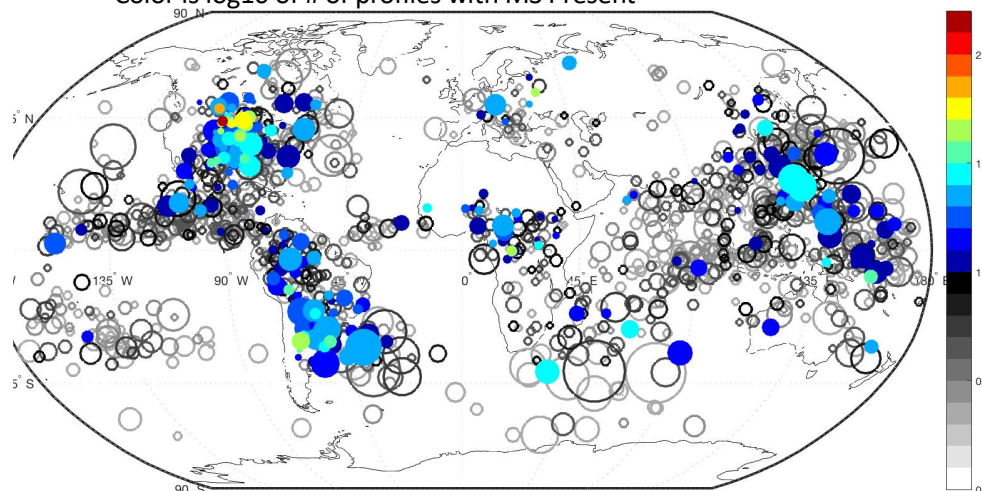
MS \ Rainy	0	1-9	10-49	50+
2-9	329K/329K	10/734	n/a	n/a
10-99	163K/157K	287/6184	0/9	0/0
100-999	57067/42K	3218/16123	103/1825	0/14
1000+	7715/3644	2164/3677	240/2553	6 / 251



Size of circle is proportional to # of profiles with MS Present  
Color is month of the year

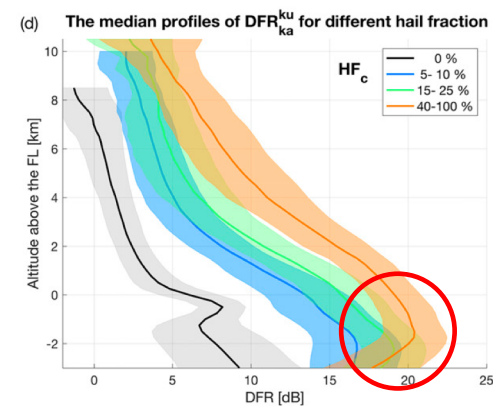
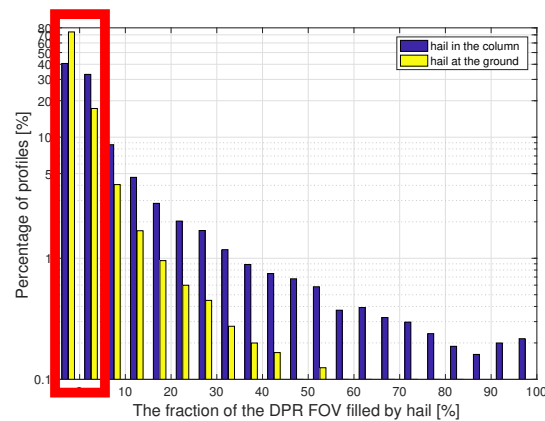


Size of circle is proportional to storm size (>1000 footprints)  
Color is log10 of # of profiles with MS Present



# Hail detection at the ground with the DPR

- 40% of DPR profiles with  $Z_{ku} > 40$  dBZ have no hail in the column
- For 75% of hail bearing columns hail does not reach the ground
- Hail detection at the ground is challenging due to: MS at the Ka-band, NUBF effects, ambiguities in the attenuation correction

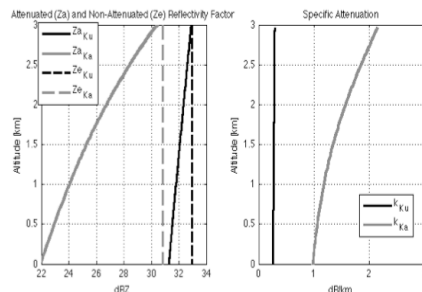
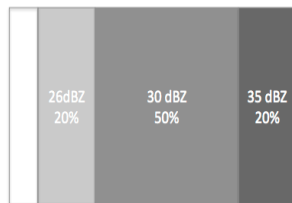
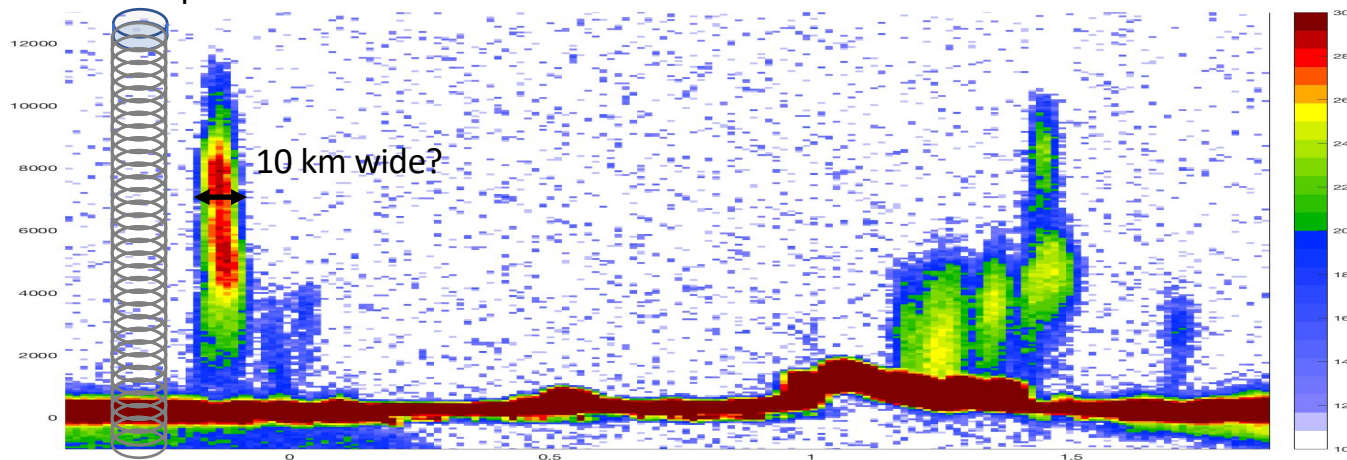


Strong hail contamination causes a DFR knee

Mroz, K., A. Battaglia, T.J. Lang, S. Tanelli, and G.F. Sacco, 2018: Global Precipitation Measuring Dual-Frequency Precipitation Radar Observations of Hailstorm Vertical Structure: Current Capabilities and Drawbacks. *J. Appl. Meteor. Climatol.*, **57**, 2161–2178, <https://doi.org/10.1175/JAMC-D-18-0020.1>

# NUBF – very short summary

8 km footprint



In attenuating conditions, it breaks the k-Z relationships:

not only they differ from what DSD and radiative transfer theory suggests,

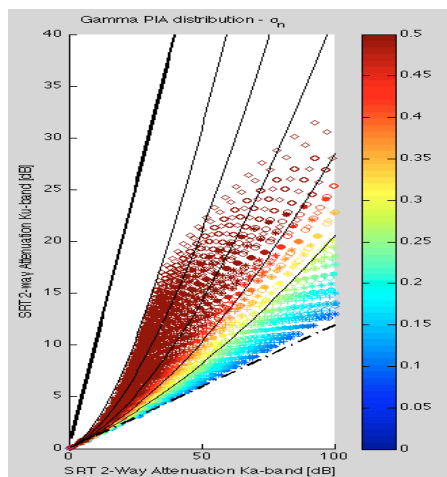
but NUBF can make them even variable within a profile even if the rain column is perfectly vertical and constant.

- In first analysis NUBF affects the non-attenuated Ze
- Most importantly, especially for Ka, it affects the observable, attenuated Zm through the non-uniform “shadow” (i.e., attenuation) caused by hydrometeors aloft.

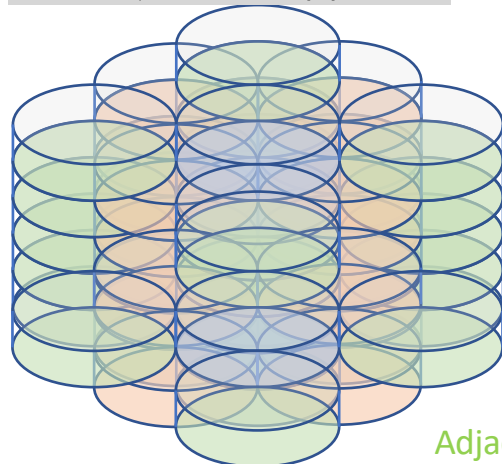
A compensating mechanism in the original TRMM/PR retrieval code was devised and it accommodated two possible assumptions about the non-uniformity within the footprint : Gamma and lognormal. The tricky part has always been how to estimate at least one parameter of variability.

Based on airborne datasets from APR-2 it was possible to verify that the Gamma distribution assumption is quite robust for the sub-beam PIA distribution, but with one significant caveat : a delta at zero is necessary to account for the “Empty Fraction”.

# NUBF – DPR available observables



- The ratio between PIA<sub>Ka</sub> and PIA<sub>Ku</sub> in uniform conditions is expected to be 6 ( $\pm 2$ )
- A departure towards the 1:1 line indicates increasingly more severe cases of NUBF
- Trigger Module calculates this ratio and uses it only where all PIA RF flags are good, and where PIA<sub>Ku</sub> > 1 and PIA<sub>Ka</sub> < 30 dB.



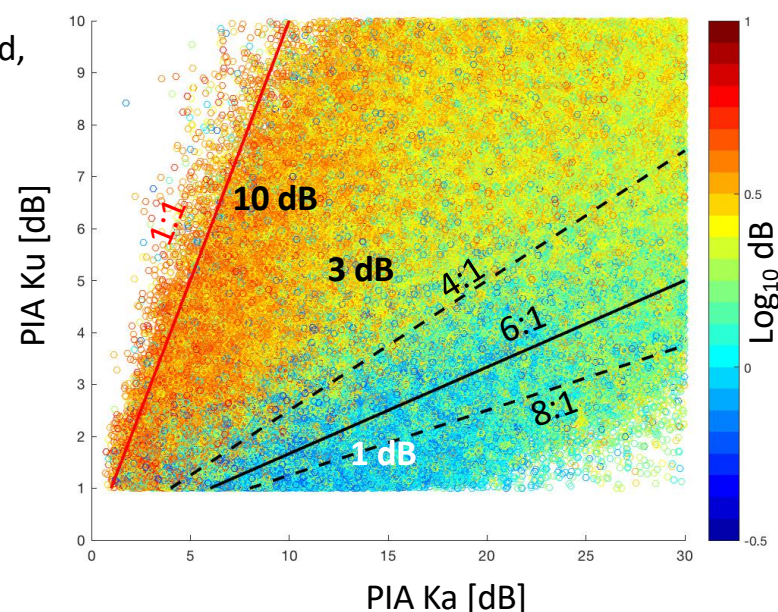
Partially overlapped  
HS Profiles

Adjacent MS Profiles

MS Profile of interest

- We can look at the variability of  $Z_{m,Ka}$  in a neighborhood, and along the column.
- As first order metrics Trigger Module calculates the column-averaged:
  - $\sigma_{Zk}$ : Variance of  $Z_{m,Ka}$  weighted by  $k_{Ka}$
  - $\sigma_{ZR}$ : Variance of  $Z_{m,Ka}$  weighted fairly in Rain
  - EF: Empty Fraction

K-weighted  $Z_{Ka}$  variance across the 9 neighbors



# NUBF – How Often does it affect DPR?

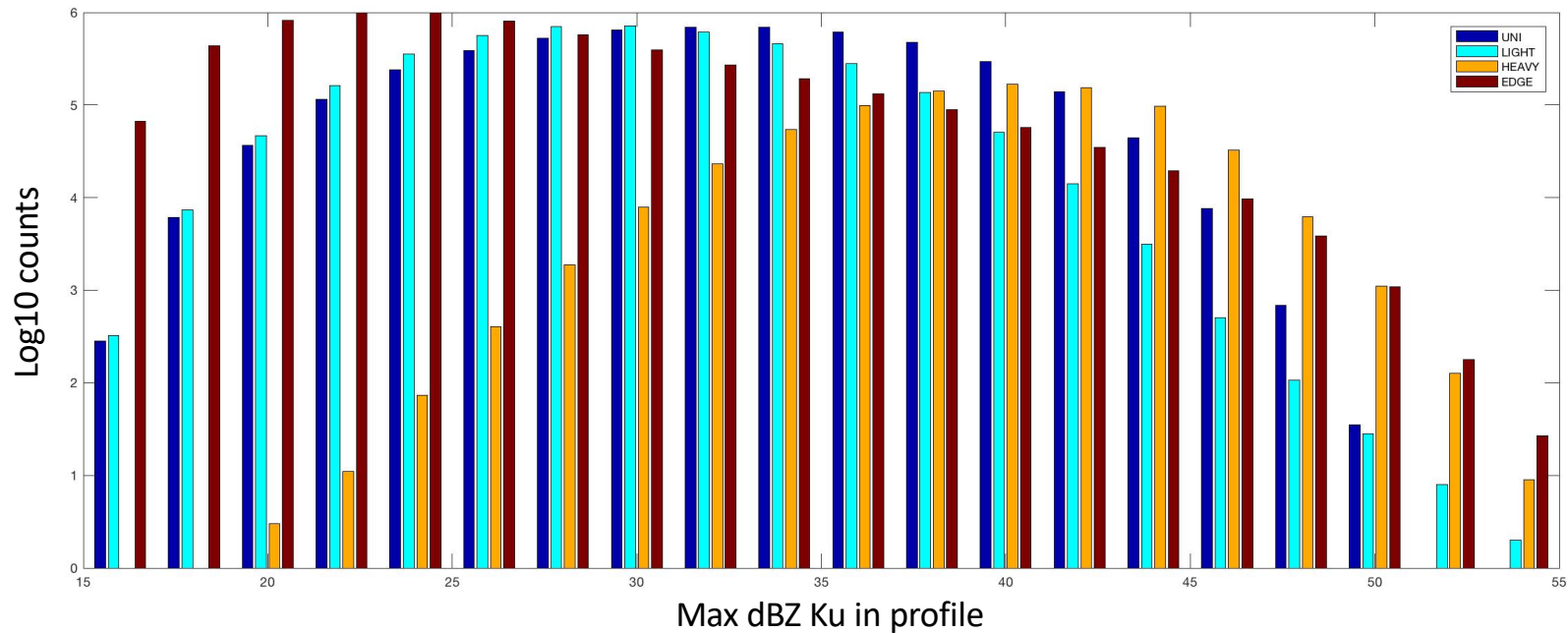
Four conditions identified:

Uniform :  $EF < 0.1$  &  $\sigma_{Zk} < 2\text{dB}$  &  $\sigma_{ZR} < 2\text{dB}$

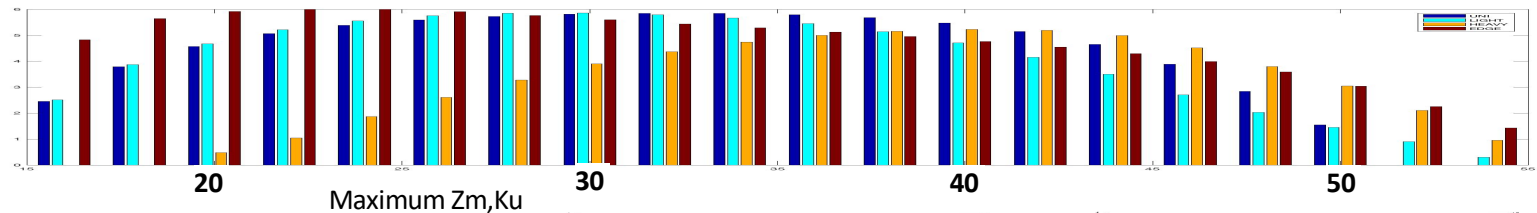
Light NUBF :  $EF < 0.1$  &  $\sigma_{ZR} > 2\text{dB}$ , but  $\sigma_{Zk} < 2\text{dB}$

Heavy NUBF :  $EF < 0.1$  &  $\sigma_{Zk} > 2\text{dB}$

Edge : Empty Fraction  $\geq 0.1$



# NUBF – How much does it affect the retrievals?

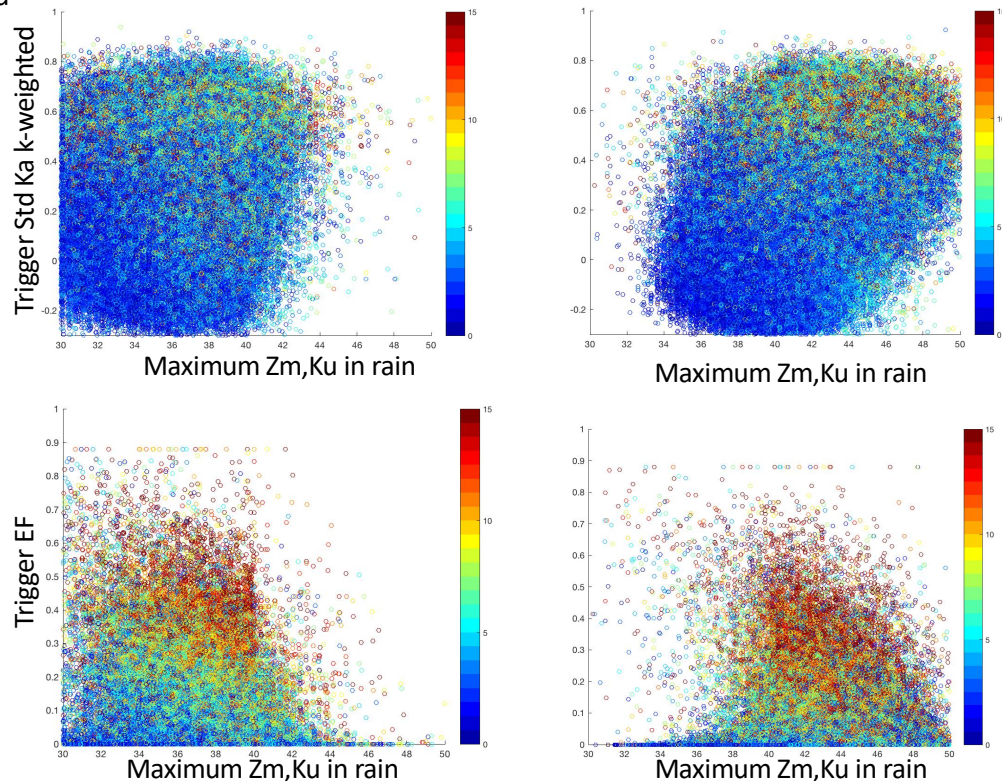


An exercise to assess impact of NUBF on retrievals is to compare

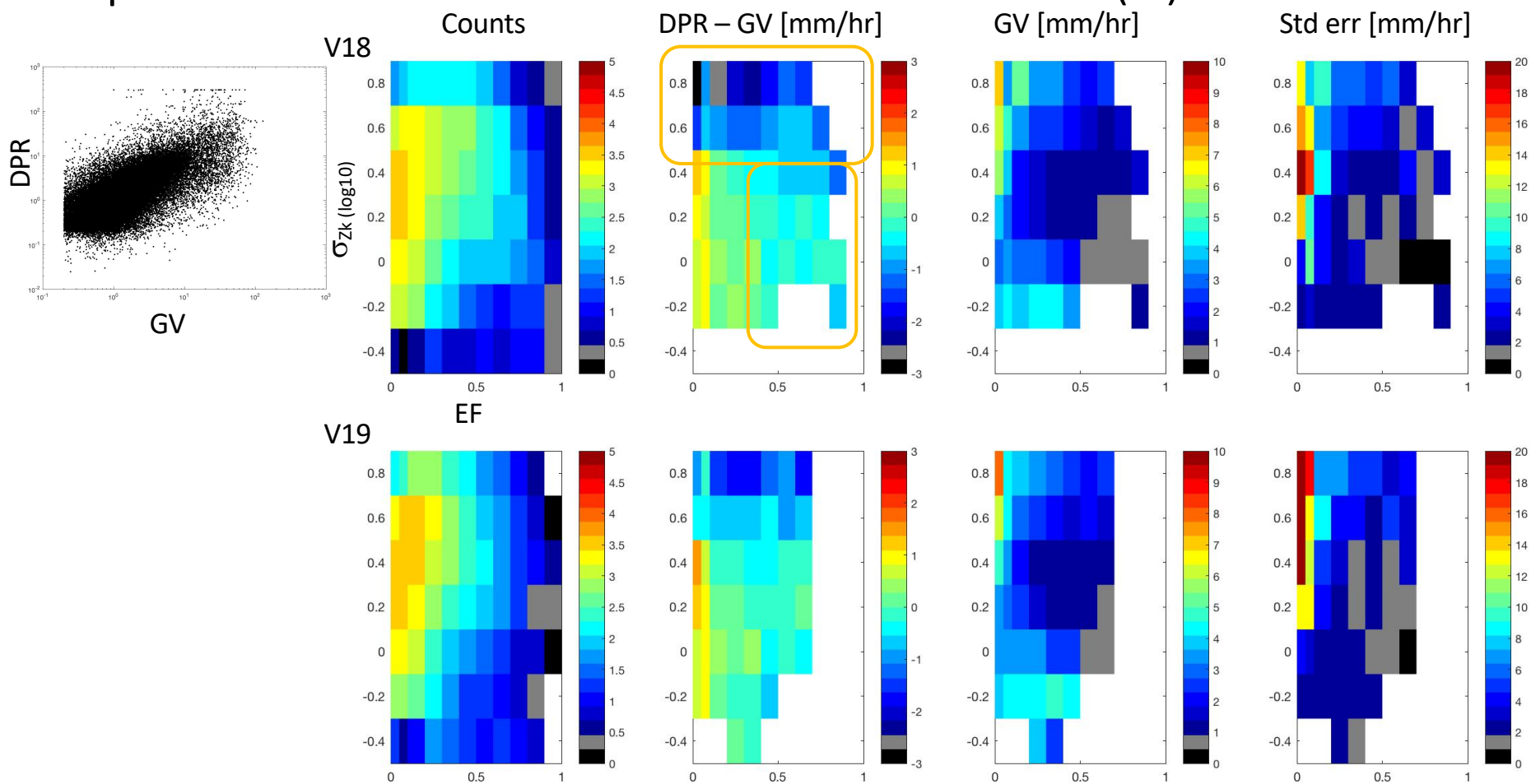
$$Z_e = a R^b$$

Where R is the Near Surface DPR estimate, and a and b are 400 and 1.53. To the maximum Zm, Ku in rain.

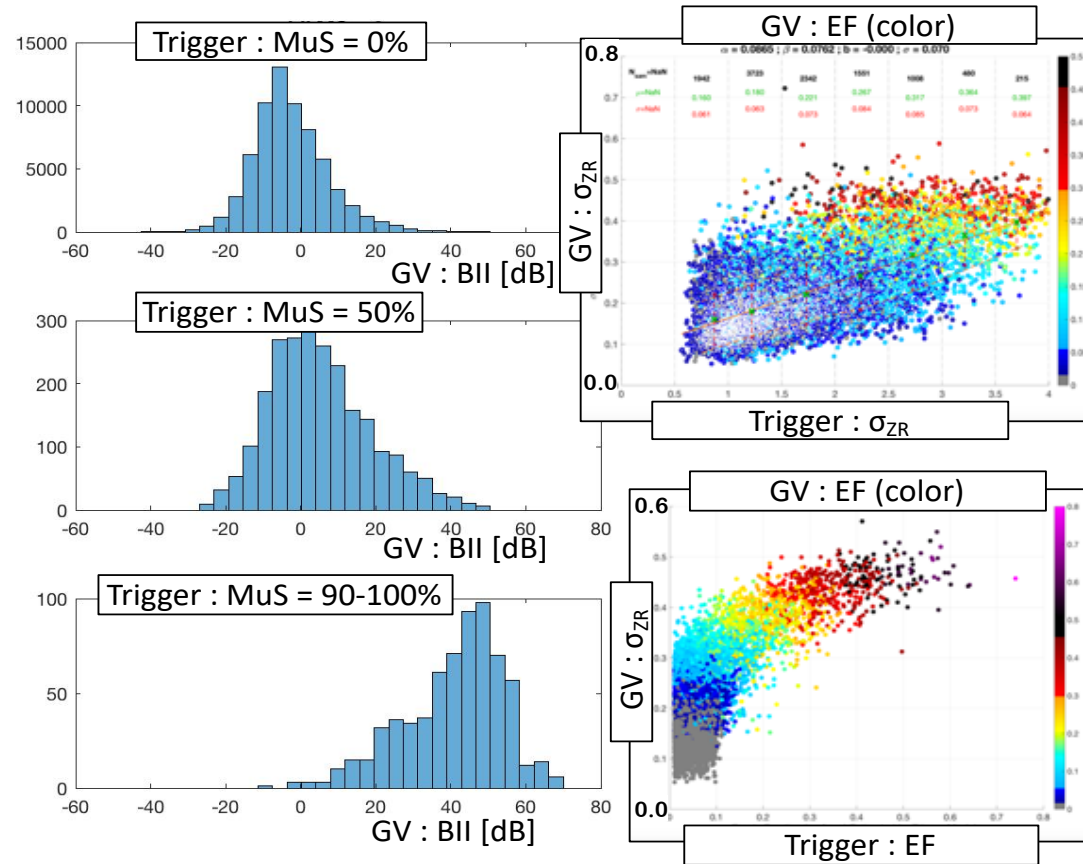
Differences of < 5 dB are to be expected, between 5 and 10 are more difficult to explain, and larger than 10 dB are definitely suspicious.



# Impact assessment with MRMS & VNDP (2)



# Validation with MRMS and VNDP



# Mitigation

- In Light NUBF cases the standard Solver should be able to reduce NUBF-induced biases by using the variability parameters
  - Separate handling of Empty Fraction and Variability of Reflectivity conditional to presence of echo should be allowed
- For profiles affected by MS, it is necessary to use solvers that include MS in their forward model.
  - These solvers must provide not only a solution, but the associated uncertainties, because in these profiles significantly larger uncertainties are to be expected.
  - When extreme MS is present, often DPR offers weak constraint to the retrieval of surface precipitation. However, it does provide excellent information on the microphysics of the frozen hydrometeors aloft, and that can be used to provide surface precipitation estimates.

